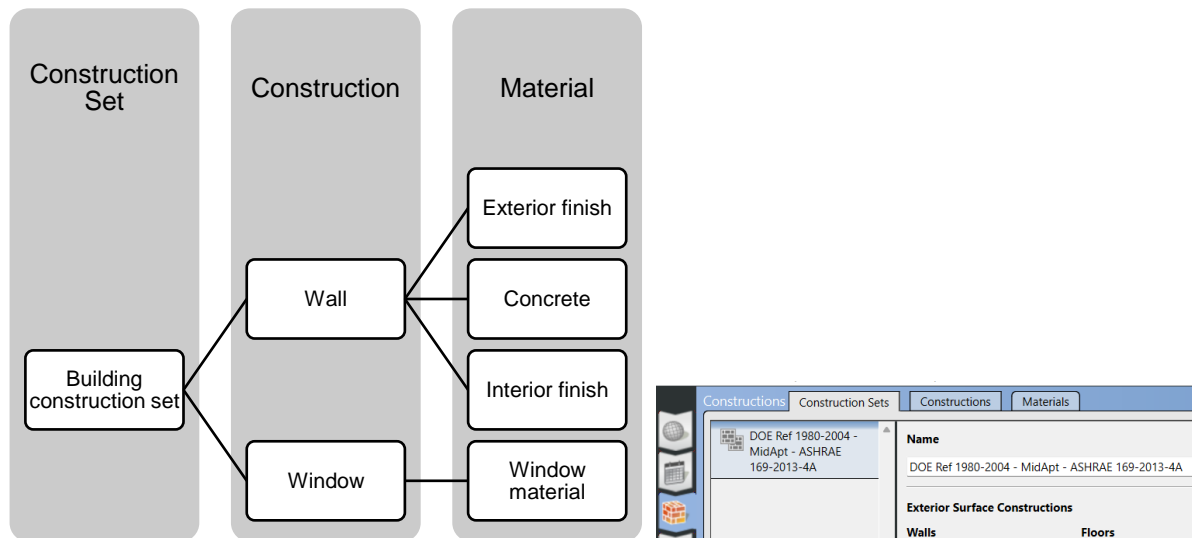


## Exercise 4



### Building envelope and heat transfer

In this exercise, you will enhance the thermal performance of the apartment building by modifying the thermal properties of the building envelope. To assist you in getting started, here is some information on the general process for working with building materials in OpenStudio.

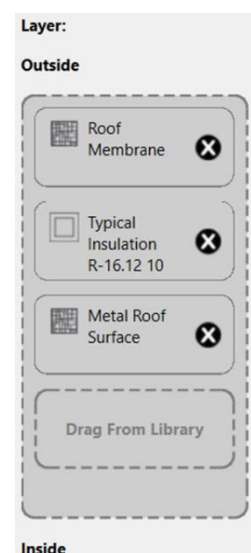
The **Constructions** tab is organized as follows: **Construction Sets** contain different **Constructions**, which are made from different **Materials**. Since, in our case, the construction set is applied to the whole building, if you edit one of the constructions or materials that is used within the construction set, you edit the whole building's material properties. The figures below show a visualization of the relationships and the relevant tabs in OpenStudio.



In this exercise, you will be editing the material properties of the windows, walls, and roofs. To simulate alternatives for the windows, walls, and roofs, it is best to create new materials and assign them to the respective constructions. When alternatives involve different ordering of material types, it is best to create new constructions and assign those constructions to the building construction set.

To create new materials or constructions, you can use the  button on the bottom left of the page. If you would like to duplicate an existing material or construction, you can use the  button. Materials can be assigned to constructions using the **Layer** properties, arranged from the exterior (exposed to the outside) to the interior (exposed to the inside).

Construction sets are edited by dragging the constructions from the right-hand panel to the respective location in the construction set.



### Step 1: Load the model starting point

It is always a good idea to periodically save your model with a new name with OpenStudi; if you named your file (for example) exercise\_3.osm, save the model again as exercise\_4.osm and work with the new file for this exercise.

For your group project, the starting model should be updated and include the strategies you implemented for your individual assignment (i.e., the strategy we saw during the previous tutorials: shading and window opening). If there were any mistakes, correct them.

For the group project, consider construction sets for your climatic zone (have a look online for typical construction sets for your location). In this tutorial, we will see only an example of an external wall, window and roof; however, in your group project, there are other “constructions” to change (see image on the side).



### Step 2: External walls

The table below provides an example of an external wall.

Material	Thickness [mm]	Conductivity [W/mK]	Density [kg/m <sup>3</sup> ]	Specific Heat [J/kgK]	Visible/Solar Absorptance	Emissivity (thermal absorptance)	R-value (for air gap only)
Wooden cladding	24	0.15	450	1800	0.50	0.84	
Horizontal wooden slats*	27	0.13	471	1600	0.78	0.84	
Vertical wooden slats*	27	0.13	471	1600	0.78	0.84	
Ventilated air gap	44	0.21	-	-	0.70	0.82	0.93
Waterproofing membrane	0.45	0.17	900	1800	0.60	0.90	
Expanded polystyrene insulation	180	0.031	15	1116	0.60	0.90	
Vapour barrier	0.22	0.40	500	1800	0.60	0.50	
Wooden covering	140	0.13	471	1600	0.78	0.84	

\* we will ignore wooden slats in Open Studio simulations; only ventilated air gap should be considered



1) Navigate to the **Constructions Sets** tab and then **Materials**.

- a. Click on **Materials**.
- b. On the bottom left of the page, click the + to add a new material object.



- c. Rename the material “Wooden cladding.”
- d. In:

**Roughness** select **MediumRough**  
**Thickness** type “0.024”  
**Conductivity** type “0.15”

Density type "450"  
 Specific Heat type "1800"  
 Thermal Absorptance type "0.84"  
 Solar Absorptance type "0.50"  
 Visible Absorptance type "0.50"

- e. On the bottom left of the page, click the + to add a new material object.



- f. Rename the material "Waterproofing membrane."

- g. In:

Roughness select Smooth  
 Thickness type "0.00045"  
 Conductivity type "0.17"  
 Density type "900"  
 Specific Heat type "1800"  
 Thermal Absorptance type "0.90"  
 Solar Absorptance type "0.60"  
 Visible Absorptance type "0.60"

- h. On the bottom left of the page, click the + to add a new material object.



- i. Rename the material "Expanded polystyrene insulation."

- j. In:

Roughness select MediumRough  
 Thickness type "0.180"  
 Conductivity type "0.031"  
 Density type "15"  
 Specific Heat type "1116"  
 Thermal Absorptance type "0.90"  
 Solar Absorptance type "0.60"  
 Visible Absorptance type "0.60"

- k. On the bottom left of the page, click the + to add a new material object.



- l. Rename the material "Vapour barrier."

- m. In:

Roughness select Smooth  
 Thickness type "0.00022"  
 Conductivity type "0.4"  
 Density type "500"  
 Specific Heat type "1800"  
 Thermal Absorptance type "0.50"  
 Solar Absorptance type "0.60"  
 Visible Absorptance type "0.60"

- n. On the bottom left of the page, click the + to add a new material object.



- o. Rename the material "Wooden covering."

- p. In:

Roughness select MediumRough  
 Thickness type "0.140"  
 Conductivity type "0.13"  
 Density type "471"  
 Specific Heat type "1600"  
 Thermal Absorptance type "0.84"

Solar Absorptance type “0.78”

Visible Absorptance type “0.78”

- q. Click on [Air Gap Materials](#).
- r. On the bottom left of the page, click the + to add a new material object.



- s. Rename the material “Ventilated air gap.”
- t. In [Thermal Resistance](#) type “0.93”

## 2) Navigate to the [Constructions](#).

- a. Click on [Constructions](#).
- b. On the bottom left of the page, click the + to add a new construction object.



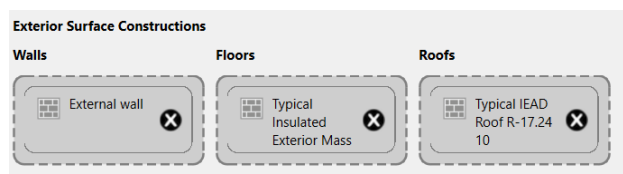
- c. Rename the construction “External wall.”
- d. On the right-hand sidebar, ensure [My Model](#) is selected at the top and scroll down to find the [Materials](#) tab. Expand the drop-down icon to find the materials we just created. Select [Wooden cladding](#) and drag this to the box named “Drag From Library.”
- e. Click on the [Air Gap Materials](#) tab. Expand the drop-down icon to find [Ventilated air gap](#), select it and drag this to the box named “Drag From Library.”
- f. Click on the [Materials](#) tab. Expand the drop-down icon to find [Waterproofing membrane](#), select it and drag and drag this to the box named “Drag From Library.” Find [Expanded polystyrene insulation](#), select it and drag this to the box named “Drag From Library.” Find [Vapour barrier](#), select it and drag and drag this to the box named “Drag From Library.” Find [Wooden covering](#), select it and drag and drag this to the box named “Drag From Library.”

## 3) Navigate to the [Construction Sets](#).

- a. Click on [DOE Ref 1980-2004 - MidApt - ASHRAE 169-2013-4A](#).
- b. On the bottom left of the page, click the x2 to duplicate the construction set object.



- c. Rename the construction “Apartment construction set.”
- d. On the right-hand sidebar, ensure [My Model](#) is selected at the top and scroll down to find the [Constructions](#) tab. Expand the drop-down icon to find the construction we just created. Select [External wall](#) and drag this to the box appropriate box, that is, in [Exterior Surface Constructions](#), under [Walls](#).



### Step 3: Windows

The image below provides an example of window.

		<b>Window 1</b> <b>Double Pane</b>	
<b>ENERGY PERFORMANCE RATINGS</b>			
U-Factor		Solar Heat Gain Coefficient	
<b>1.0</b>		<b>0.85</b>	
<b>ADDITIONAL PERFORMANCE RATINGS</b>			
Visible Transmittance		Air Leakage	
<b>0.51</b>		<b>0.2</b> <small>(U.S./I-P)</small>	<b>1.0</b> <small>(Metric/SI)</small>
Condensation Resistance		—	
<b>51</b>			

1) Navigate to the [Constructions Sets](#) tab  and then [Materials](#).

- a. Click on [Simple Glazing System Window Materials](#).
- b. On the bottom left of the page, click the + to add a new material object.



- c. Rename the material “Double pane.”
- d. In:
  - [U-Factor](#) type “1.0”
  - [Solar Heat Gain Coefficient](#) type “0.85”
  - [Visible Transmittance](#) type “0.51”

4) Navigate to the [Constructions](#).

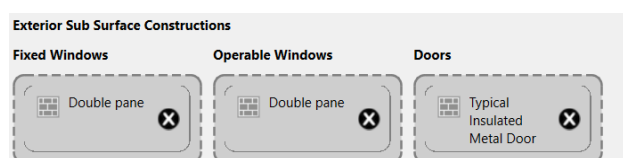
- a. Click on [Constructions](#).
- b. On the bottom left of the page, click the + to add a new construction object.



- c. Rename the construction “Window double pane.”
- d. On the right-hand sidebar, ensure [My Model](#) is selected at the top and scroll down to find the [Simple Glazing System Window Materials](#) tab. Expand the drop-down icon to find the materials we just created. Select [Double pane](#) and drag this to the box named “Drag From Library.”

5) Navigate to the [Construction Sets](#).

- a. Click on [Apartment construction set](#).
- b. On the right-hand sidebar, ensure [My Model](#) is selected at the top and scroll down to find the [Constructions](#) tab. Expand the drop-down icon to find the construction we just created. Select [Double pane](#) and drag this to the box appropriate box, that is, in [Exterior Sub Surface Constructions](#), under [Fixed Windows](#) and [Operable Windows](#).



## Step 4: Roof

The table below provides an example of roof.

Material	Thickness [mm]	Conductivity [W/mK]	Density [kg/m <sup>3</sup> ]	Specific Heat [J/kgK]	Visible/ Solar Absorptance	Emissivity (thermal absorptance)
Gravel	16	0.36	1840	840	0.29	0.28
Bitumen elastomeric membrane	4	0.23	1100	1000	0.60	0.95
Polyurethane insulation	180	0.034	35	1400	0.60	0.90
Vapour barrier	0.22	0.5	980	1800	0.60	0.56
OSB panels	25	0.13	650	1700	0.60	0.92



1) Navigate to the [Constructions Sets](#) tab and then [Materials](#).

- a. Click on [Materials](#).
- b. On the bottom left of the page, click the + to add a new material object.



- c. Rename the material "Gravel."
- d. In:
  - [Roughness](#) select [MediumRough](#)
  - [Thickness](#) type "0.016"
  - [Conductivity](#) type "0.36"
  - [Density](#) type "1840"
  - [Specific Heat](#) type "840"
  - [Thermal Absorptance](#) type "0.28"
  - [Solar Absorptance](#) type "0.29"
  - [Visible Absorptance](#) type "0.29"
- e. On the bottom left of the page, click the + to add a new material object.



- f. Rename the material "Bitumen elastomeric membrane."
- g. In:
  - [Roughness](#) select [Smooth](#)
  - [Thickness](#) type "0.004"
  - [Conductivity](#) type "0.23"
  - [Density](#) type "1100"
  - [Specific Heat](#) type "1000"
  - [Thermal Absorptance](#) type "0.95"
  - [Solar Absorptance](#) type "0.60"
  - [Visible Absorptance](#) type "0.60"
- h. On the bottom left of the page, click the + to add a new material object.



- i. Rename the material "Polyurethane insulation."
- j. In:
  - [Roughness](#) select [MediumRough](#)
  - [Thickness](#) type "0.180"

Conductivity type "0.034"  
 Density type "35"  
 Specific Heat type "1400"  
 Thermal Absorptance type "0.90"  
 Solar Absorptance type "0.60"  
 Visible Absorptance type "0.60"

- k. On the bottom left of the page, click the + to add a new material object.



- l. Rename the material "Vapour barrier\_roof."

- m. In:

Roughness select **Smooth**  
 Thickness type "0.00022"  
 Conductivity type "0.5"  
 Density type "980"  
 Specific Heat type "1800"  
 Thermal Absorptance type "0.56"  
 Solar Absorptance type "0.60"  
 Visible Absorptance type "0.60"

- n. On the bottom left of the page, click the + to add a new material object.



- o. Rename the material "OSB panels."

- p. In:

Roughness select **MediumRough**  
 Thickness type "0.025"  
 Conductivity type "0.13"  
 Density type "650"  
 Specific Heat type "1700"  
 Thermal Absorptance type "0.92"  
 Solar Absorptance type "0.60"  
 Visible Absorptance type "0.60"

## 2) Navigate to the **Constructions**.

- a. Click on **Constructions**.  
 b. On the bottom left of the page, click the + to add a new construction object.

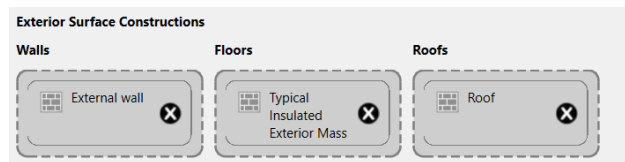


- c. Rename the construction "Roof."  
 d. On the right-hand sidebar, ensure **My Model** is selected at the top and scroll down to find the **Materials** tab. Expand the drop-down icon to find the materials we just created. Select **Gravel** and drag this to the box named "Drag From Library." Find **Bitumen elastomeric membrane**, select it and drag and drag this to the box named "Drag From Library." Find **Polyurethane insulation**, select it and drag and drag this to the box named "Drag From Library." Find **Vapour barrier\_roof**, select it and drag and drag this to the box named "Drag From Library." Find **OSB panels**, select it and drag this to the box named "Drag From Library."

## 3) Navigate to the **Construction Sets**.

- a. Click on **Apartment construction set**.  
 b. On the right-hand sidebar, ensure **My Model** is selected at the top and scroll down to find the **Constructions** tab. Expand the drop-down icon to find the

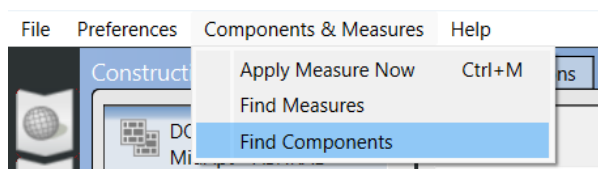
construction we just created. Select **Roof** and drag this to the box appropriate box, that is, in **Exterior Surface Constructions**, under **Roofs**.



## Step 5: Load component

Instead of creating materials by hand, it is possible to import existing materials from the OS library

- 1) In the top bar, click on **Components & Measures** and then **Find Components**



- 2) Go in **Material** and then **Opaque**
  - a. Search for the material of interest and select it.
  - b. Click **Download**.
  - c. Close the current window and return to the main OpenStudio window.
  - d. On the right-hand panel, ensure **Library** is selected at the top and scroll down to find the **Materials** tab. Expand the drop-down icon to find the materials we just downloaded. Select it and drag it to the box named "Drag From Library."
  - e. Now, the material should be added to the model.

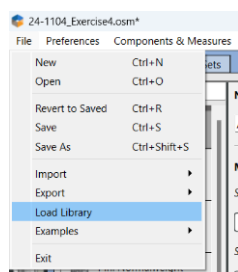
- 3) If you cannot add the material to your model by following these steps, there is a workaround. Go to the following link:

<https://github.com/BuildingComponentLibrary/nrel-components/tree/v0.3/lib/components/Material/Opaque>

- a. Browse and search the material of interest.
- b. Select the file "<material\_of\_interest>.osm" and download it by clicking on the three dots in the top-right corner. Save the file within your project folder.



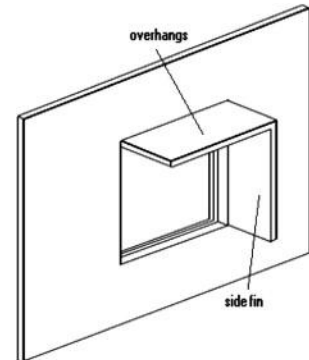
- c. In the top bar, click on **File** and then **Load Library**



- d. Search for the file you just downloaded and open it.
- e. On the right-hand panel, ensure **Library** is selected at the top and scroll down to find the **Materials** tab. Expand the drop-down icon to find the materials we just imported. Select it and drag it to the box named “Drag From Library.”
- f. Now, the material is added to the model.

## Step 6: Overhang and Sidefin


Sidefins and overhangs are traditional building forms and when properly designed can prove solar control and enhancing daylighting. Overhangs and sidefins can be characterised in terms of a projection factor. For examples, for overhangs the projection factor is the ratio of the projection of the overhang from the window surface to the distance from the window sill to the bottom of the overhang.



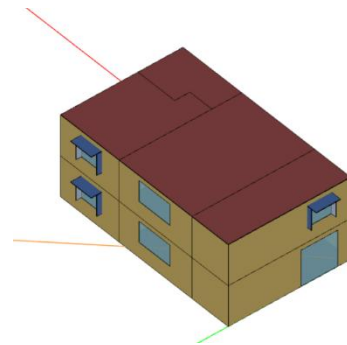
More information about overhang and fin can be found at the following link <https://bigladdersoftware.com/epx/docs/25-1/input-output-reference/group-thermal-zone-description-geometry.html#shadingoverhangprojection>

(search for “Shading:Overhang:Projection” and


“Shading:Fin:Projection.” Note: the majority of the option described here are not available in OpenStudio)

- 1) Navigate to the **Geometry** tab  and select the **Editor** tab at the top of the page.

- a. Select **Components** at the top of the page.
- b. Click on the expand button and for the window “W\_160.140” set **Overhang Projection Factor** to 0.5, and **Fin Projection Factors** to 0.25. The **Overhang Projection Factor** allows for specifying the depth of the overhang as a fraction of the window’s height. The **Fin Projection Factors** allows for specifying the depth of the overhang as a fraction of the window’s width. This object allows for specification of both fins for the window. This object allows.
- c. Merge your model again by clicking **Merge with Current OSM**.



- 2) Navigate to the **Constructions Sets** tab  and then **Constructions**.

- a. Click on **Constructions**.
- b. On the bottom left of the page, click the + to add a new construction object.
 
- c. Rename the construction “Shading\_space.”

- d. On the right-hand sidebar, ensure [My Model](#) is selected at the top and scroll down to find the [Materials](#) tab. Expand the drop-down icon to find [F08 Metal surface](#). Select it and drag it to the box named “Drag From Library.”

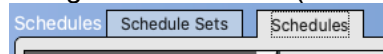
3) Navigate to the [Construction Sets](#).

- a. Click on [Apartment construction set](#).
- b. On the right-hand sidebar, ensure [My Model](#) is selected at the top and scroll down to find the [Constructions](#) tab. Expand the drop-down icon to find the construction we just created. Select [Shading\\_space](#) and drag this to the box appropriate box, that is, in [Other Constructions](#), under [Space Shading](#).




4) Navigate to the [Schedules](#) tab 

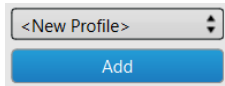
- a. Navigate to [Schedules](#) (not [Schedule Sets](#))



- b. On the bottom left of the page, click the + to add a new schedule object.

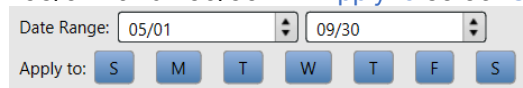


- c. Under [Schedule Type](#), select [Fractional](#)
- d. Rename the schedule “Overhang schedule.”
- e. Next to [Run Period Profiles](#) click the + [Run Period Profiles](#)  and then



click [Add](#).

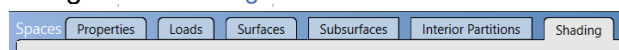
- f. In [Schedule Rule Name](#) rename the schedule to “Summer.” In [Date Range](#) type “05/01” and “09/30.” In [Apply to](#) select [S](#), [M](#), [T](#), [W](#), [T](#), [F](#) and [S](#).



- g. In [Schedule Day Name](#) rename the schedule to “Summer.”
  - a. Change the value. To do this, hover your mouse over the horizontal line at the top of the graph, type 0, and hit enter. (A value of 0 imply an opaque element).
  - h. Click on [Default](#).
  - a. Change the value. To do this, hover your mouse over the horizontal line at the top of the graph, type 1, and hit enter. (A value of 1 imply a transparent element).

5) Navigate to the [Spaces](#) tab 

- a. Navigate to [Shading](#)



- a. Select the [My Model](#) tab on the right-hand panel and navigate to the newly created [Overhang schedule](#) under [Ruleset Schedules](#). Drag the schedule to the box labelled [Transmittance Schedule](#) in the row corresponding to [0-A1.B](#). Assign the schedule manually one at the time. If you attempt to assign multiple schedules at a time using the [Apply to Selected](#) the program will crash.